Collider-Accelerator Department Operations Overview
DOE Nuclear Physics Program Review

Derek I. Lowenstein
June 30, 2004

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BROOKHAVEN
NATIONAL LABORATORY

COLLIDER-ACCELERATOR DEPARTMENT

Circa June 2004

Mission: ŅTo develop, improve and operate the suite of particle/heavy ion accelerators used to carry out the program of accelerator-based experiments at BNL; support of the experimental program including design, construction and operation of the beam transports to the experiments, plus support of detector and research needs of the experiments; to design and construct new accelerator facilities in support of the BNL and national missions. The C-A Department supports an international user community of over 1500 scientists. The Department performs all these functions in an environmentally responsible and safe manner under a rigorous conduct of operations approach.Ó

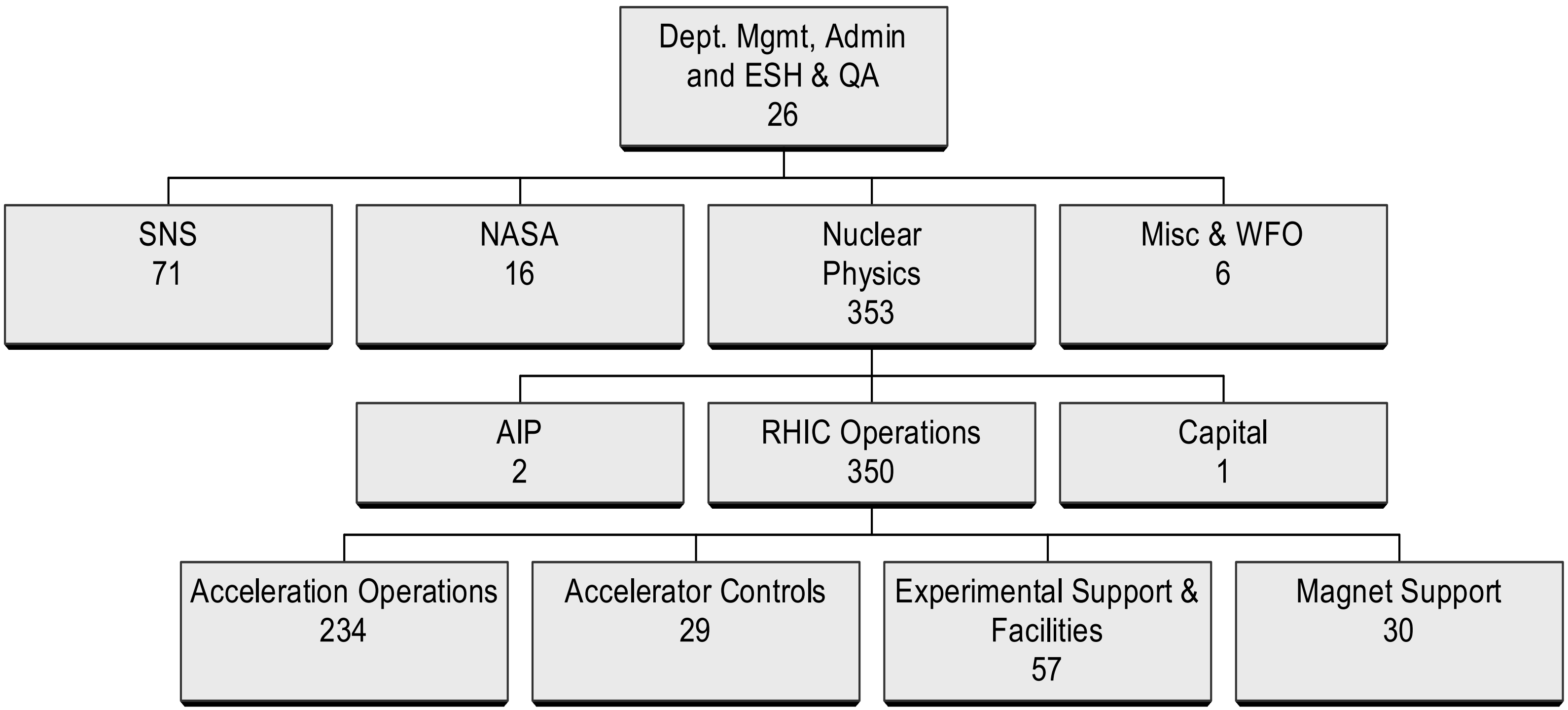
Staff: The Collider-Accelerator Department headcount is:

	Total	NP*	SNS	NASA	Other
Ph.D. Scientists	49	41	6	1	1
Postdoctoral Fellows	6	5	1	0	0
Engineers/Professional	144	114	23	5	2
Designers/Technicians	196	155	32	6	3
Admin./Clerical	24	21	2	1	0
Totals	419	336	64	13	6

*Does not include ~39 Magnet Division employees charged to NP and SNS.
Additional support ~13 FTEs are purchased as Laboratory assigned trades.

Collider Accelerator Department

(Programmatic FTEs 474)*



* Reflects FTE data circa June 2004

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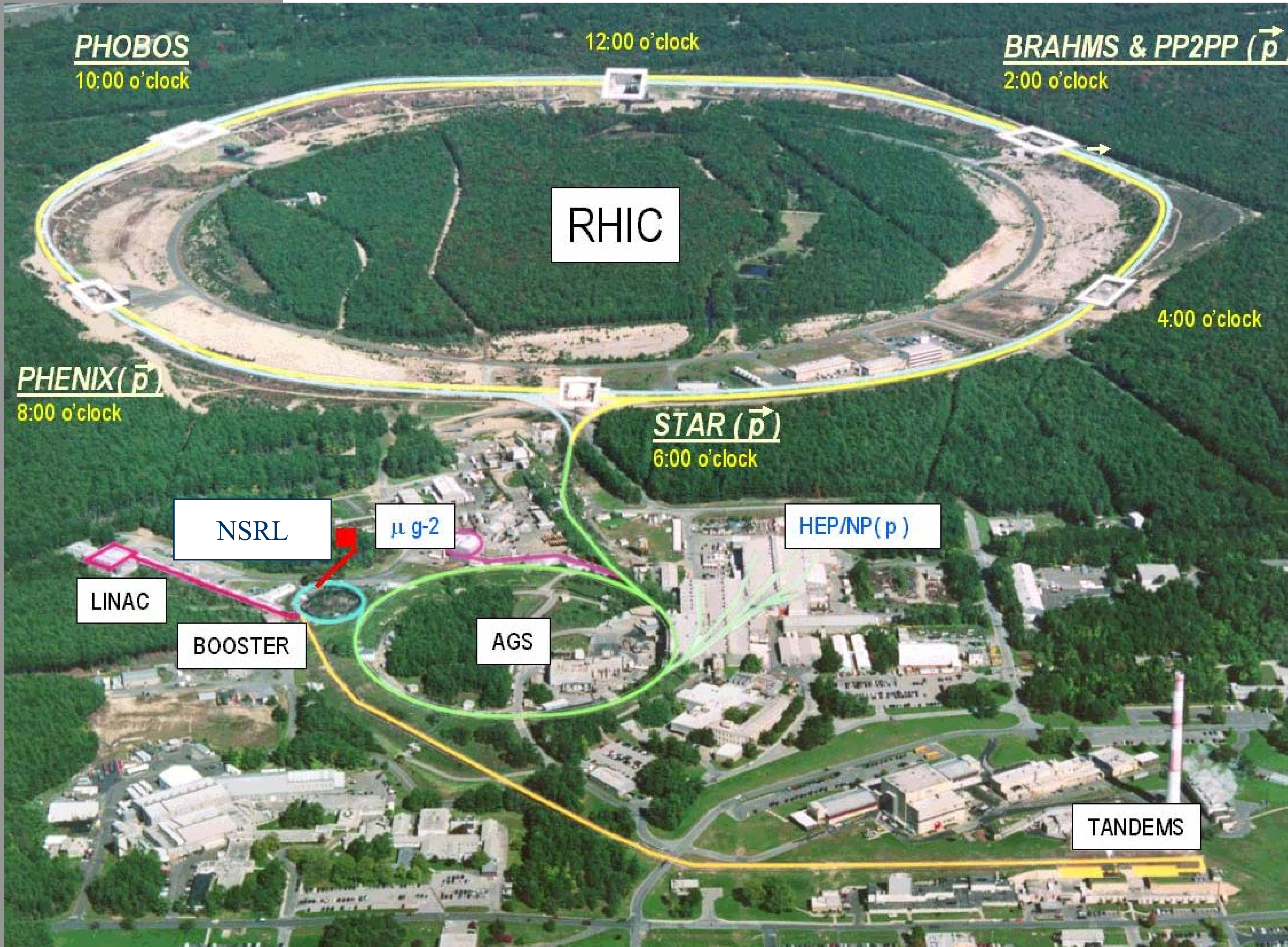
Funding: Estimated DOE Funding (initial new B/A) for FY 2004 ($M to date) comprises

Fund Type	DOE NP	SNS	NASA	Other	Totals
Operating	92.5	0.0	3.5	2.8	98.8
Equipment	1.8	0.0	0.0	0.0	1.8
Construction/AIP	2.9	11.4	0.0	0.0	14.3
Totals	97.2	11.4	3.5	2.8	114.9



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C-AD Program Areas

- **RHIC**
  - Heavy Ion (DOE-NP).
  - Polarized Proton (DOE-NP).
- **AGS**
  - RSVP (NSF HEP (Pending), $12M/year operations).
    - Awaiting a DOE/NSF MOU
  - E949 operations (NSF HEP, under consideration).
  - Radiobiology (NASA, conjunction with NSRL).
- **Tandem**
  - Commercial Users ($1M yearly sales).
- **Linac**
  - Isotope Production (DOE-NE, *problematic, parasitic to limited linac operations).*
- **Booster**
  - NASA Space Radiation Laboratory (NASA, $5M/year, plus $2M for Medical and Biology Departments).

C-AD Program Areas

- **Projects**
  - Spallation Neutron Source (DOE-BES, complete FY 2005, $118M)
  - RSVP (NSF-pending, start FY 2005, $150M, $35M to C-A)
  - Electron Beam Ionization Source injector (DOE-NP + NASA, start date ? $18M))
  - NSRL second beam line (NASA, FY2006? $15M)
  - Neutrino proposal (under development)
  - Cyclotron Isotope Research Center (DOE-NE,start ? ~$30M)
- **R&D**
  - electron-cooling of ions(DOE NP, BNL PDF, US Navy, AES, Jlab)
    - ZDR being developed
  - stochastic - cooling of RHIC ions
    - Beam studies continue
  - eRHIC design (Bates MIT, Novosibirsk)
    - ZDR completed
  - Polarized He3 source (MIT Bates, Caltech)

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ERL Sources of Funding ($k)

	FY03	FY04	FY05(Exp./Req.)	FY06
(Exp./Req.)				
DOE	900	2000	2000	2000
BNL Prog. Dev/GPP	600	1200	1200	600
SBIR Tech-X	100	750	500	
JTO Cryo-module	350	300	100	
ONR Photo-cathode		490	490	
JTO ERL			300	300
JTO Photoinj.			600	600
Total	1950	4740	5190	3500

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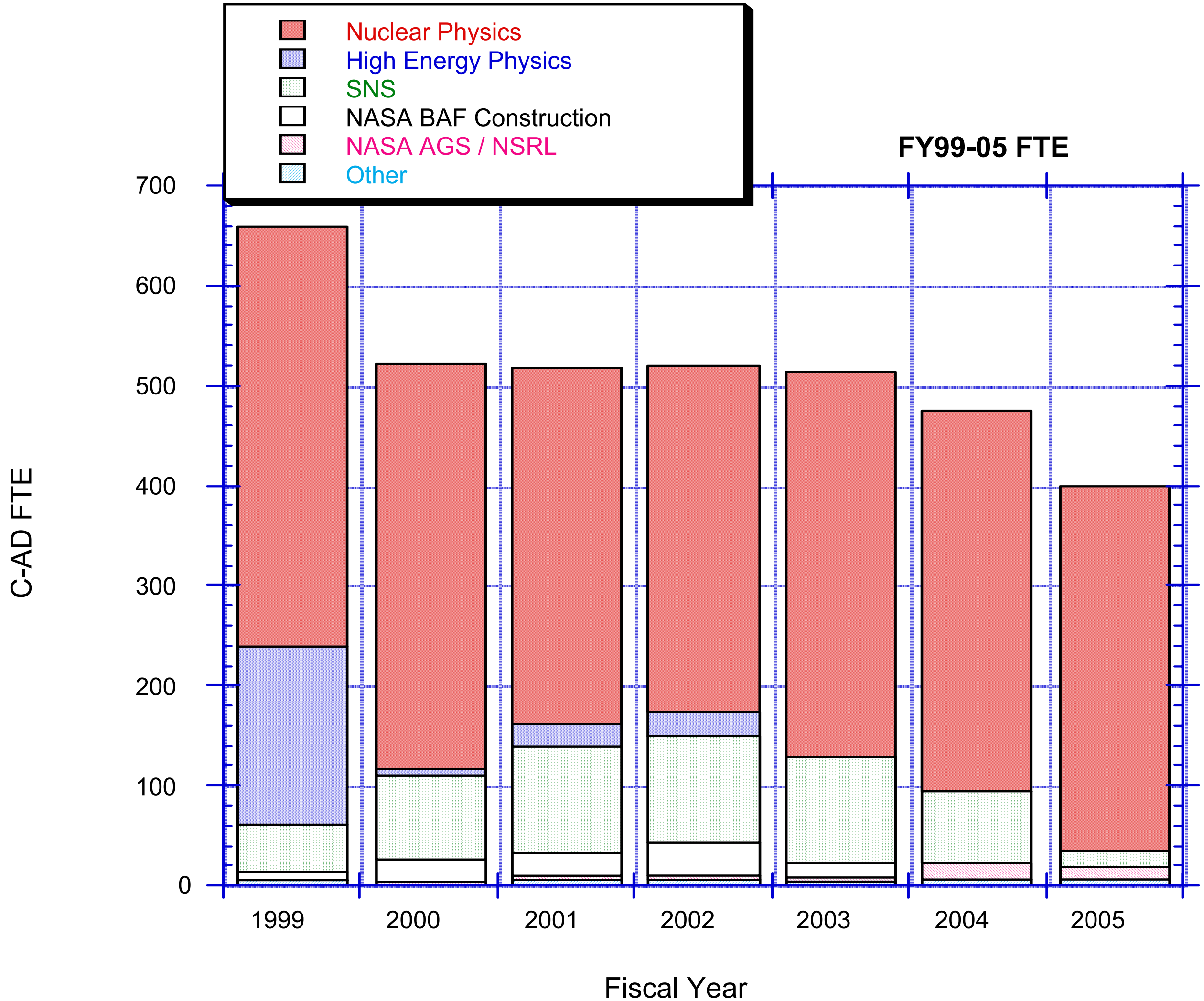
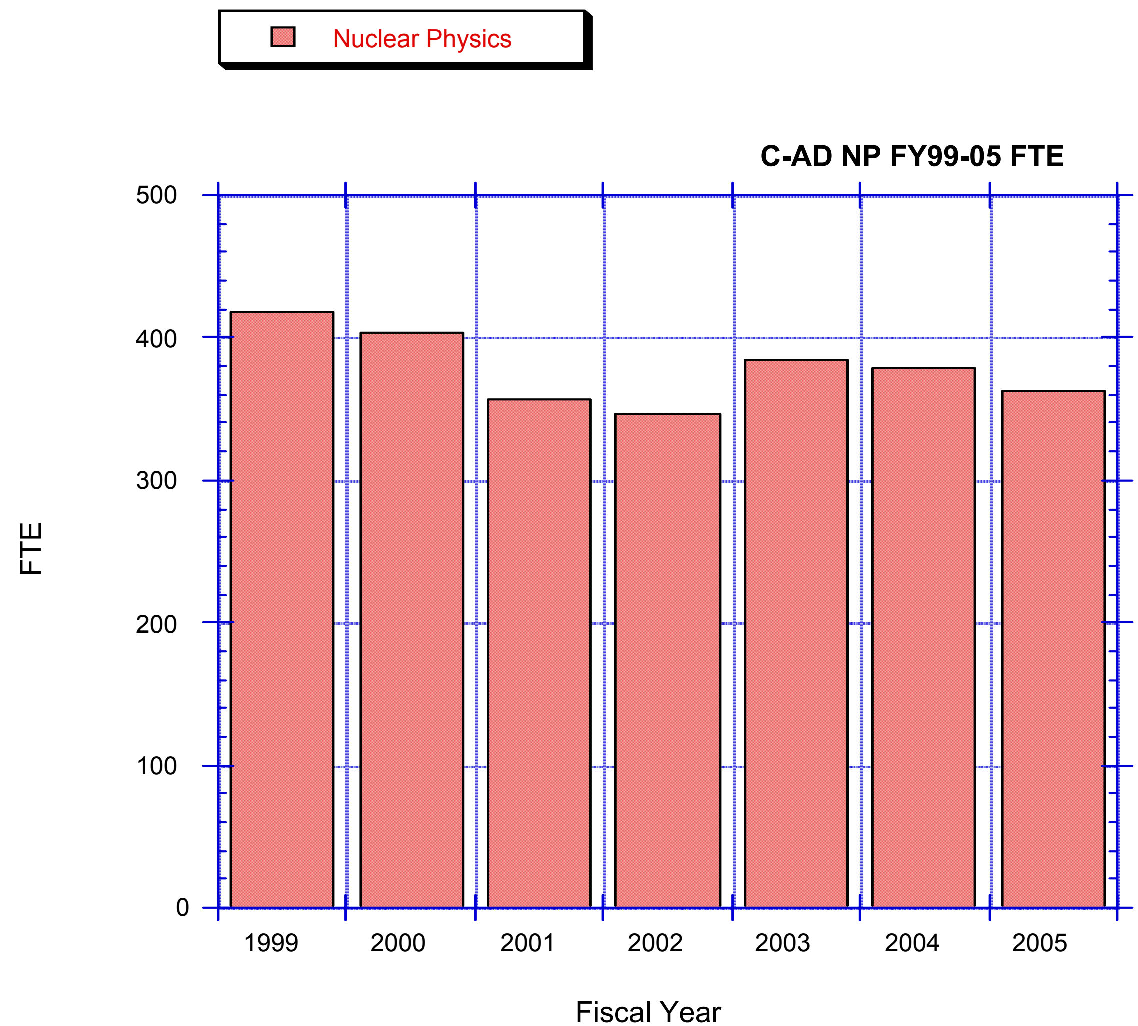
- FY2005 Issues:
  - **DOE unfunded infrastructure mandate** forces increased space charge rate at 9.8% each year from FY05-FY07
    - Increased space charge reduces available operating funds by ~$1M in FY2005
  - M&S budget remains ~$1M below an adequate level.
    - FY2004 received $1M power rebate. Added to M&S budget
  - EBIS construction funds are uncertain
    - NASA is interested to join DOE in funding EBIS
      - NASA has proposed that they would supply 25% of funding starting in FY2005 if DOE commits in FY2006.
    - Tandem intensity is limiting RHIC luminosity performance. Increasing EBIS electron beam current from 10 to 20 milliamps (> 2.5 Tandem output)
  - SNS manpower has been a matrixed resource to the RHIC program. 65 FTE reduction in FY2005.
  - **New NYPA power rates go into effect in July 2005. FY2006 problem.**
  - Electron - cooling r&d is planned to remain at $2M
    - Should be increased to at least $3M
    - BNL and US Navy funds have allowed for faster progress


Nuclear Physics
High Energy Physics
SNS
NASA BAF Construction
NASA AGS / NSRL
Other
FY99-05 FTE
700
600
500
400
300
200
100
0
C-AD FTE
1999
2000
2001
2002
2003
2004
2005
Fiscal Year



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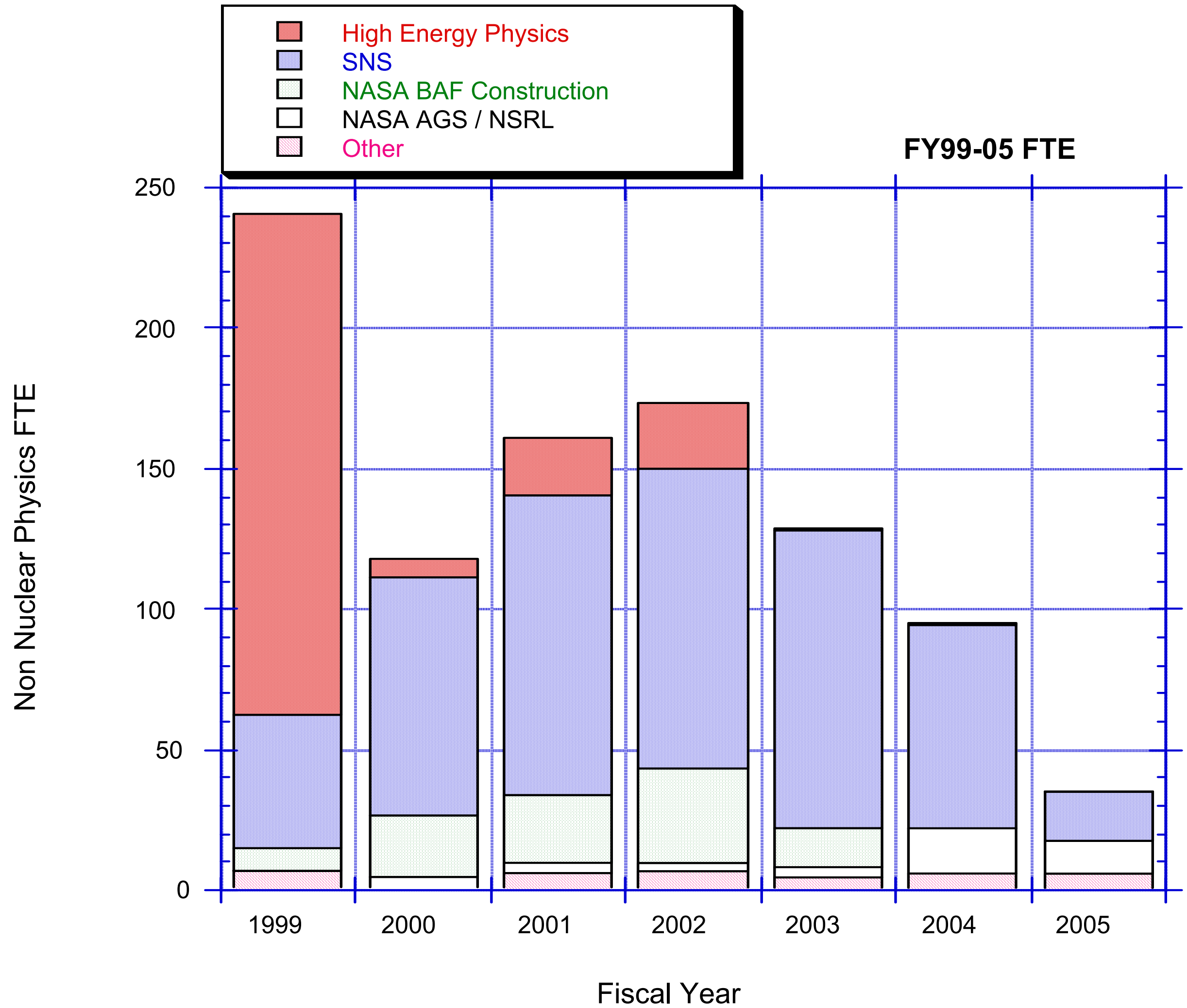

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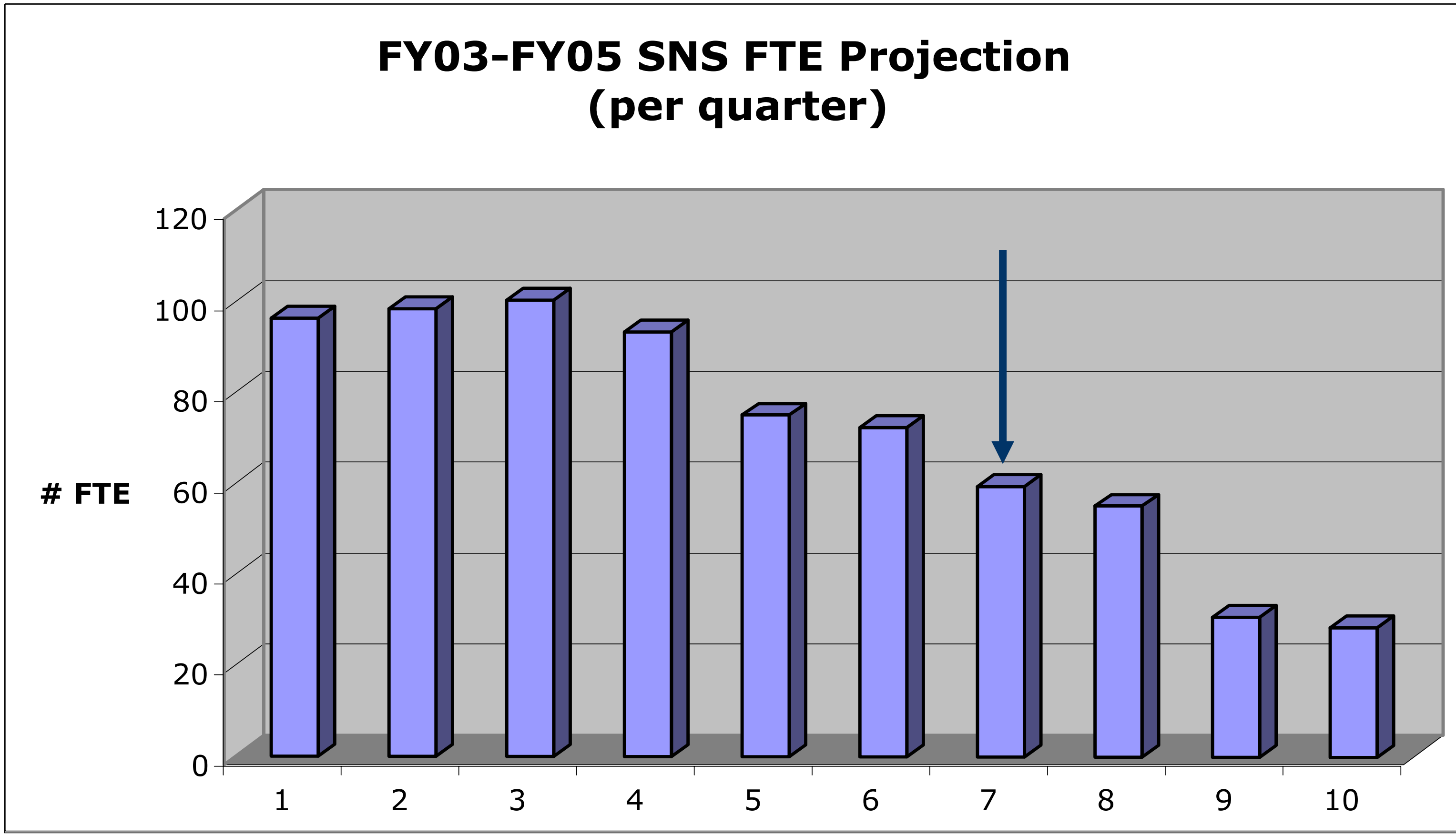

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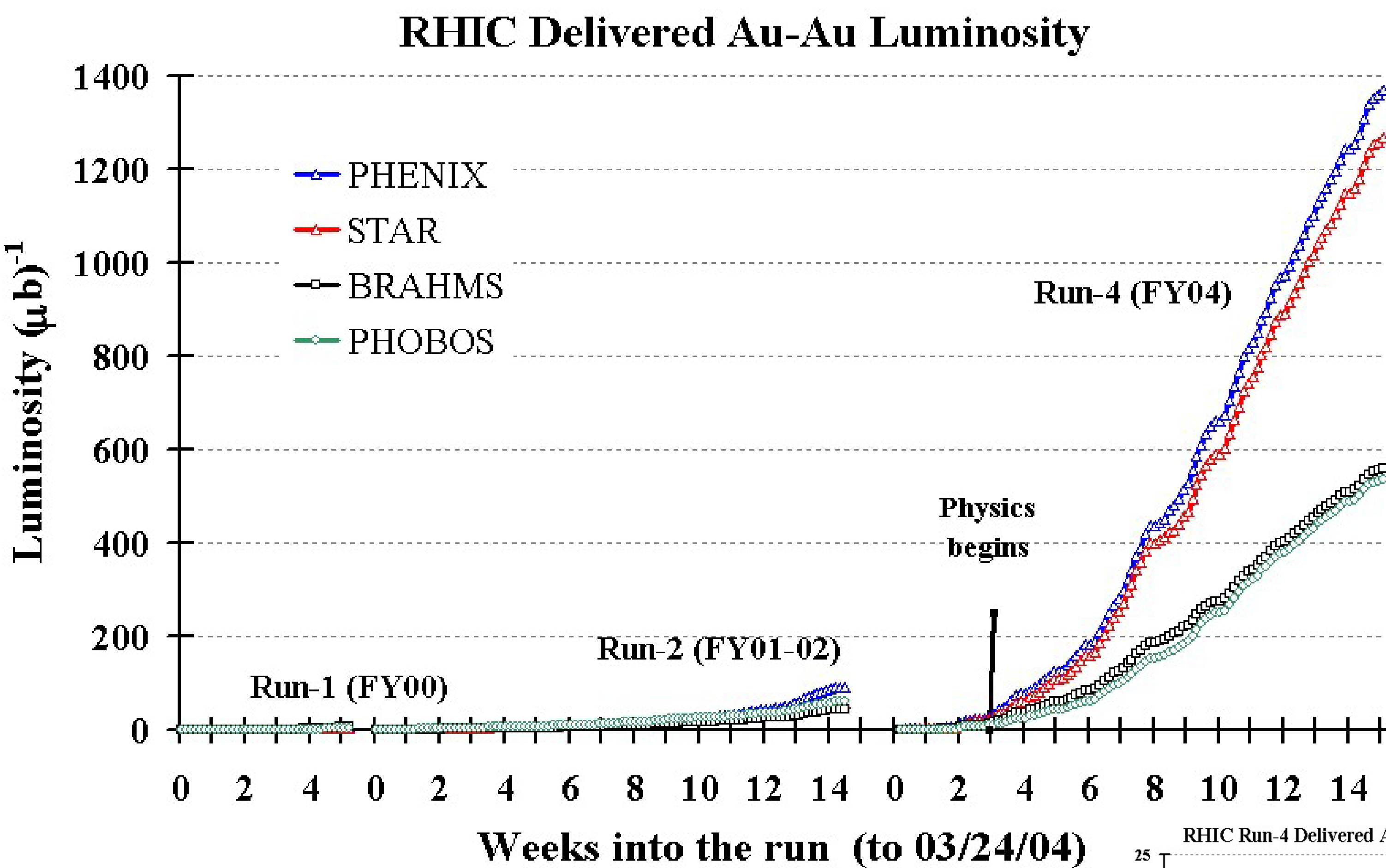
RHIC Performance

RHIC

1. More operational flexibility than other hadron colliders
   - Variation in particle species, also asymmetric
     → So far Au+Au, d+Au, p+p, others possible
   - Variation in energy
     → Au+Au at 10,31, 66, 100 GeV/u
     → p↑+p ↑ at 100 GeV (250 GeV planned in year after next)
   - Variation in lattice
     → Low β^* in most cases (1-3 m)
     → Large β^* for small angle scattering experiments (>10 m)
     → Polarity change in large experimental magnets about every 2 weeks
2. Four experiments (2 large, 2 small), different preferences
   - Need to avoid that any one experiment becomes bottleneck
3. Short runs (~30 weeks/year), with multiple modes
   - Significant amount of set-up time required
4. Short luminosity lifetime with heavy ions (~ few hours)
   - Fast refills essential

RHIC Run-4 –Au-Au Operation at 100GeV/u & 31.2GeV/u

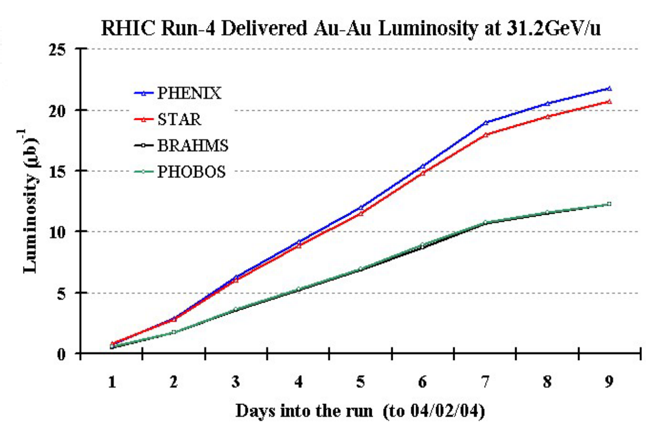


maximum projection

physics target

minimum projection

	100GeV/u $(\mu b)^{-1}$	Relative to Run-2	31.2GeV/u $(\mu b)^{-1}$
PHENIX	**1370**	**15x**	**21.8**
STAR	**1270**	**21x**	**20.7**
BRAHMS	**560**	**13x**	**12.2**
PHOBOS	**540**	**7x**	**12.3**



Achieved parameters

Mode	No of bunches	Ions/bunch [10^9]	β* [m]	Emittance [μm]	L_{peak} [$cm^{-2}s^{-1}$]	$L_{store\ ave}$ [$cm^{-2}s^{-1}$]	L_{week}
Au-Au [Run-4]	45	1.1	1	15-40	15×10^{26}	5×10^{26}	160 μb^{-1}
d-Au [Run-3]	55	110/0.7	1	15	12×10^{28}	3×10^{28}	4.5 nb^{-1}
p↑-p↑ [Run-4]	55	70	1	20-30	6×10^{30}	3×10^{30}	0.6 pb^{-1}
Au-Au design	56	1	2	15-40	9×10^{26}	2×10^{26}	50 μb^{-1}
p↑ -p↑ design	56	100	2	20	5×10^{30}	4×10^{30}	1.2 pb^{-1}
p↑-p↑ upgrade*	112	200	1	20	80×10^{30}	65×10^{30}	20 pb^{-1}

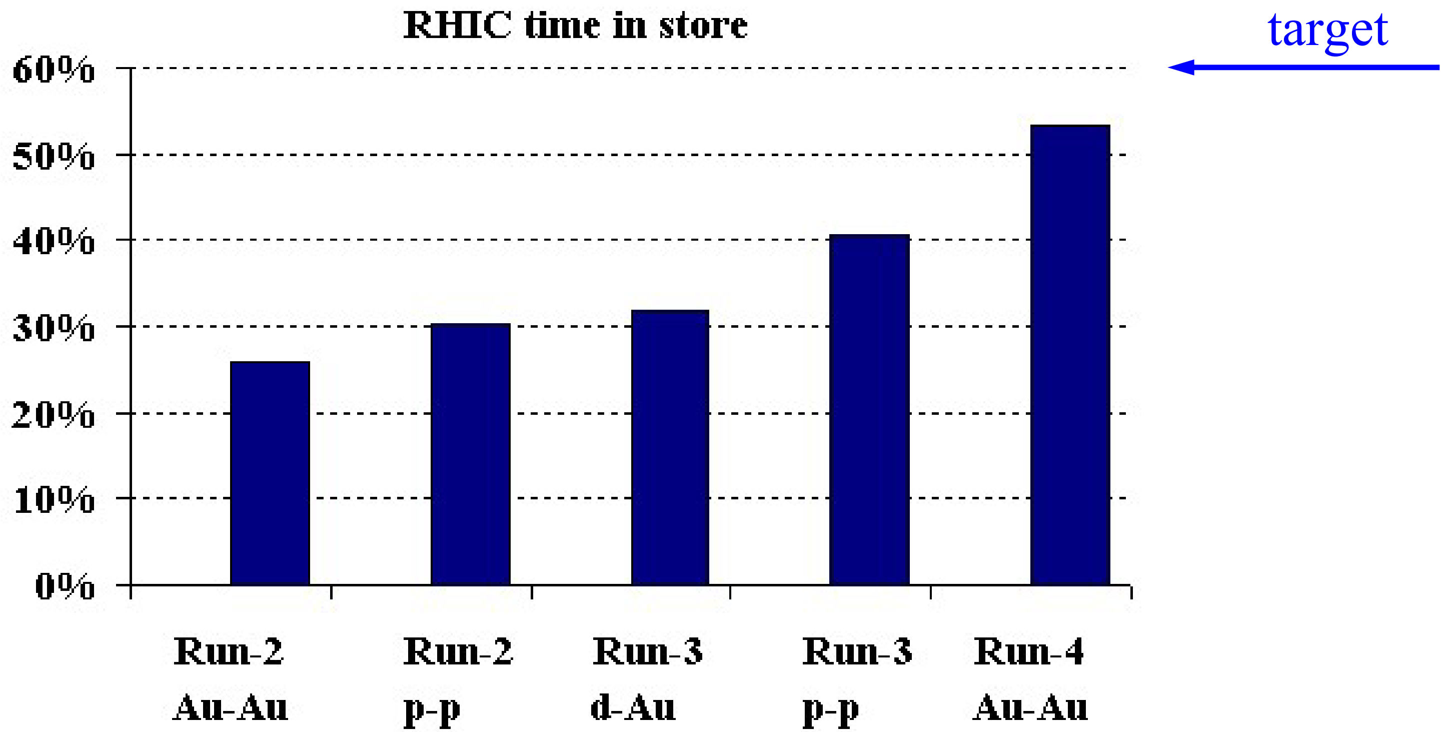
* future goal

RHIC Run-4 – Au-Au operation at 100GeV/u & 31.2GeV/u

Major achievements Au-Au:

- Start-up/ramp-up in 4 weeks (1 week less than planned)
- Consistent high bunch intensity from injector ($\geq 10^9$Au)
- Time in store increased to 53% (65% at 31.2GeV/u)
- Reliable, almost complete rebucketing into storage rf
- Steering and collimator setting time reduced to 10min
- Best 7 days delivered 179 μb^{-1} to Phenix (2x Run-2)
- Set-up for 31.2GeV/u run in less than 2 days

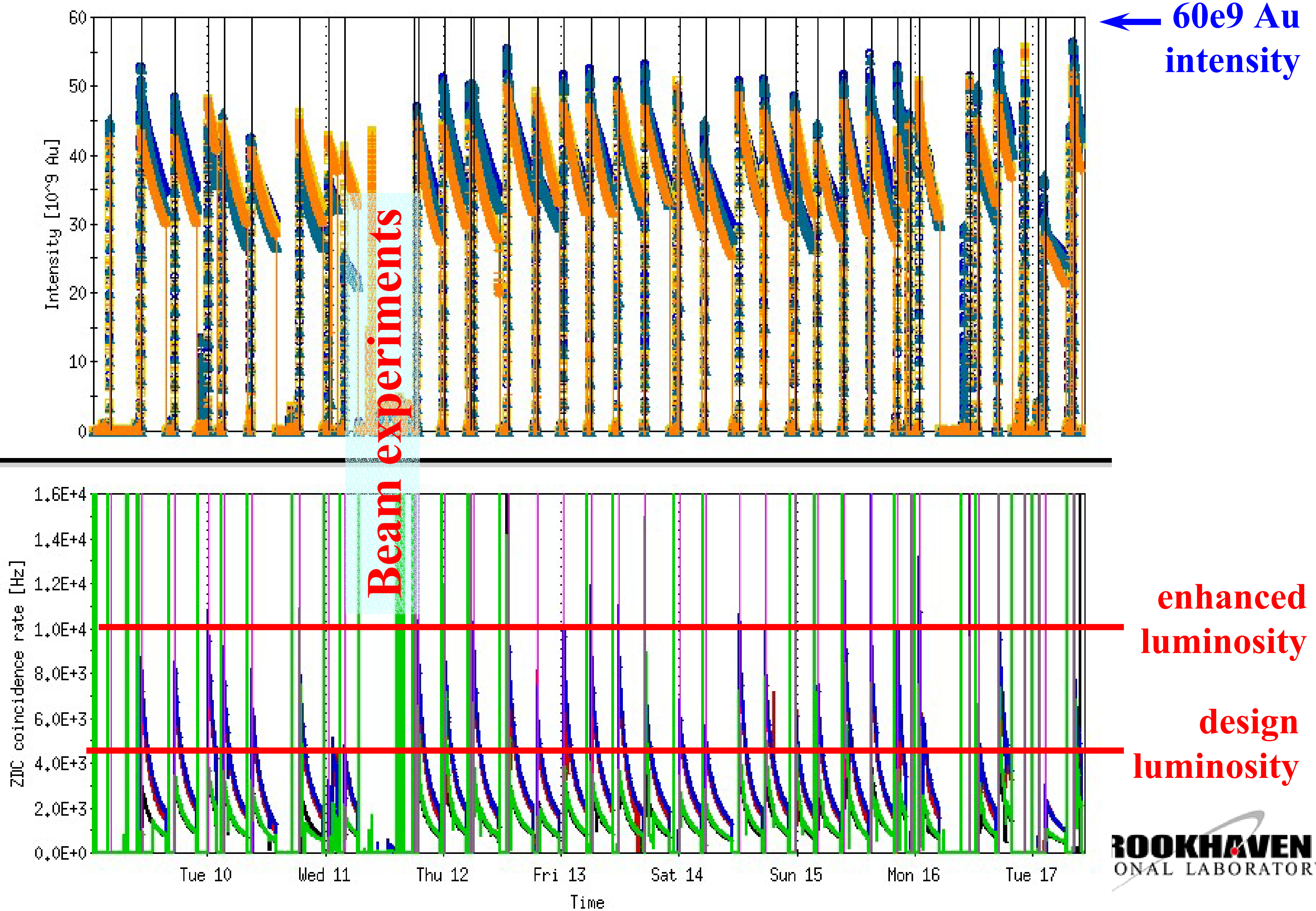
RHIC time in store mode



More time in stores through
- Reduced number of quenches by 15% compared to Run-3 (several days)
- Eliminated ice-ball formation at corrector leads (several days)
- Better ramp maintenance, orbit correction after each ramp (several days)
- Resolved AtR cooling and software problems (~ 2 days)
- More reliable corrector power supplies (~ 2 day)
- Faster down ramps (1-2 days)

RHIC Run-4 – one week of physics stores

Week 9 Feb to 17 Feb [66% of calendar time in store]



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Enhanced Luminosity Goals

(before e-cooling, about to be reached when RSVP starts, 2008)

For Au-Au, average per store, 4 IRs

$L = 8{\cdot}10^{26} cm^{-2}s^{-1}$ at 100GeV/u

For p↑-p↑ average per store, 2 IRs

$L = 6{\cdot}10^{31} cm^{-2}s^{-1}$ at 100GeV

$L = 1.5{\cdot}10^{32} cm^{-2}s^{-1}$ at 250GeV

with **70% polarization**

Major achievements p↑-p↑:

(M. Bai talk)

Coordinators: H. Huang AGS
M. Bai RHIC

- New warm snake in AGS,
  increases polarization by ~20%
- Max polarization from AGS 50%, consistently 40%
- Max polarization in RHIC 45%, consistently 35%
- Polarized H-jet commissioned
- Luminosity with 2 experiments >10^{31}cm^{-2}s^{-1}
  (28 bunches, no polarization)
- Repeated stores with P=35%, L=$5 \cdot 10^{30}$cm^{-2}s^{-1} initially
  (56 bunches, 4 experiments)

RHIC Run-4 – The polarized H jet target for RHIC operational (Bravar talk)

DELIVERED
ON
SCHEDULE
&
BUDGET

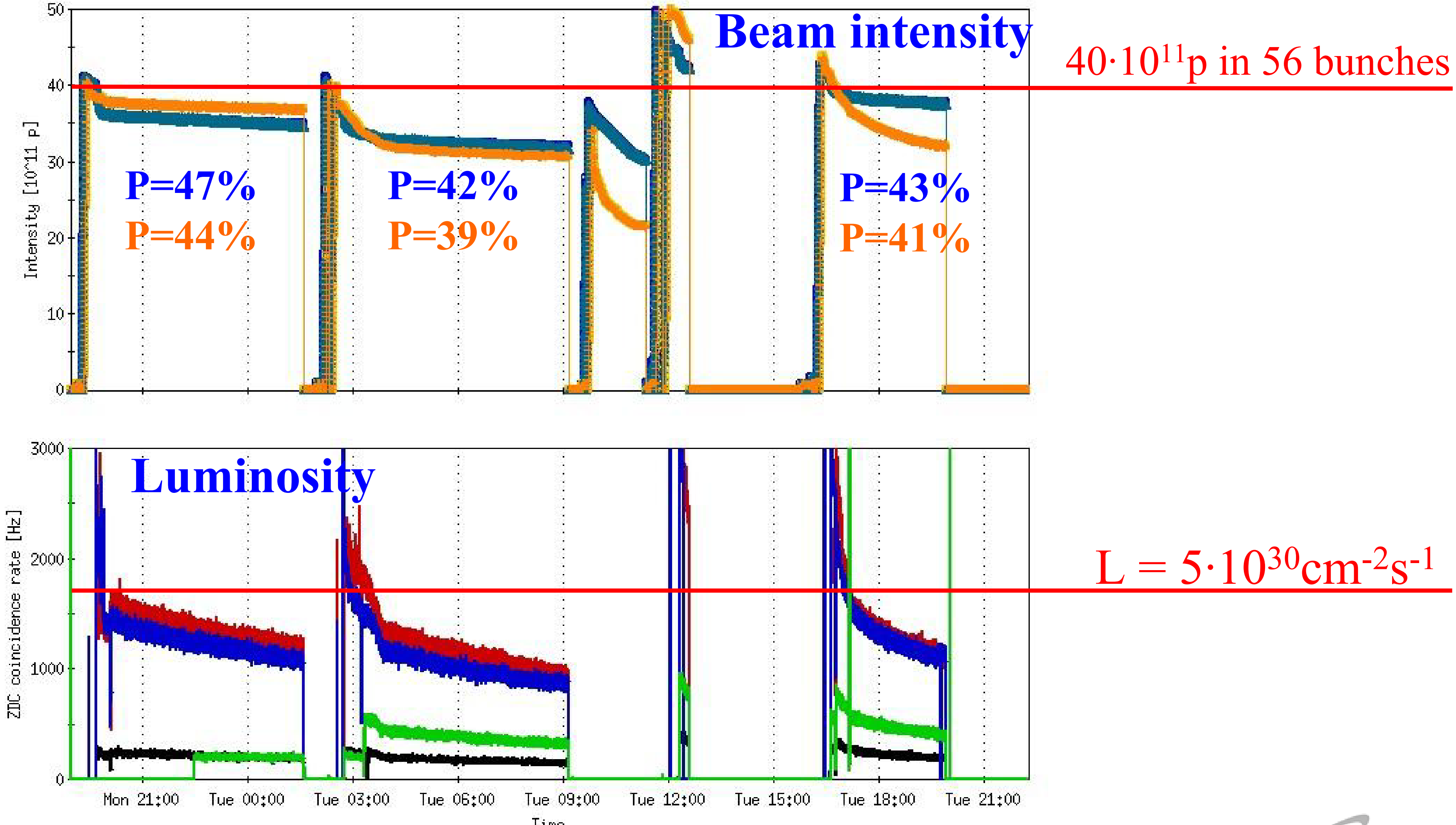
RHIC Run-5 – Ion operation (W. Fischer talk)

Likely a species scan:

- Waiting for proposals
- Consider Si^{14+} and Fe^{26+}, Ni^{28+}, Cu^{29+}
- Performance similar to Au^{79+} in Run-4 with
  - 10^{11} or more charges per bunch possible
  - Luminosity improvements due to vacuum upgrade, and reduced intra-beam scattering
- All above species are possible, preference for intensity/reliability of injector performance:
  1. Si^{14+} gas stripping
  2. Ni^{28+}, Cu^{29+} 2-3x Fe intensity at Booster
  3. Fe^{26+}

RHIC Run-5 – Polarized proton operation (M. Bai talk)

Repeated stores with higher luminosity and higher polarization
Commission AGS cold snake



Collider-Accelerator Department

Machine Advisory Committee

Brookhaven National Laboratory, March 10-11 2004

Committee

Oliver Boine-Frankenheim, GSI; Alexander Chao, SLAC; Jean-Pierre Delahaye, CERN; David McGinnis, FNAL; L. Merminga, JLAB, Ferdinand Willeke, DESY(Chair)

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- The committee is very impressed by the progress with polarized protons. The RHIC team is pioneering this field for the benefit of the whole community. There has been steady progress in the last decades which enables an exciting physics program. The committee wants to congratulate the RHIC and AGS team in the achievement of polarized protons in collisions and is looking forward to further progress. The innovative idea of adding two additional helical Siberian snakes is expected to allow avoiding intrinsic depolarizing resonances.

- The committee considers the observation of Schottky signals within the range of 4-8 GHz which do not exhibit a coherent line spectrum as very encouraging. In view of this recent progress, stochastic cooling of high energy bunched ion beams in RHIC appears to be possible. The success of this program would be a major breakthrough in accelerator physics and should have a large impact on the operation of hadron storage rings. The committee would like to strongly support the bunched beam stochastic cooling program.

- The committee strongly recommends launching a project as soon as possible to replace the present Tandem facility by an EBIS source followed by the RFQ and 2 MeV/u LINAC.

- Many issues of the cooler project have already been addressed and appear to be well covered by the R&D plans. However there are possible areas of concern which were not covered sufficiently by the presentations to the committee such as:

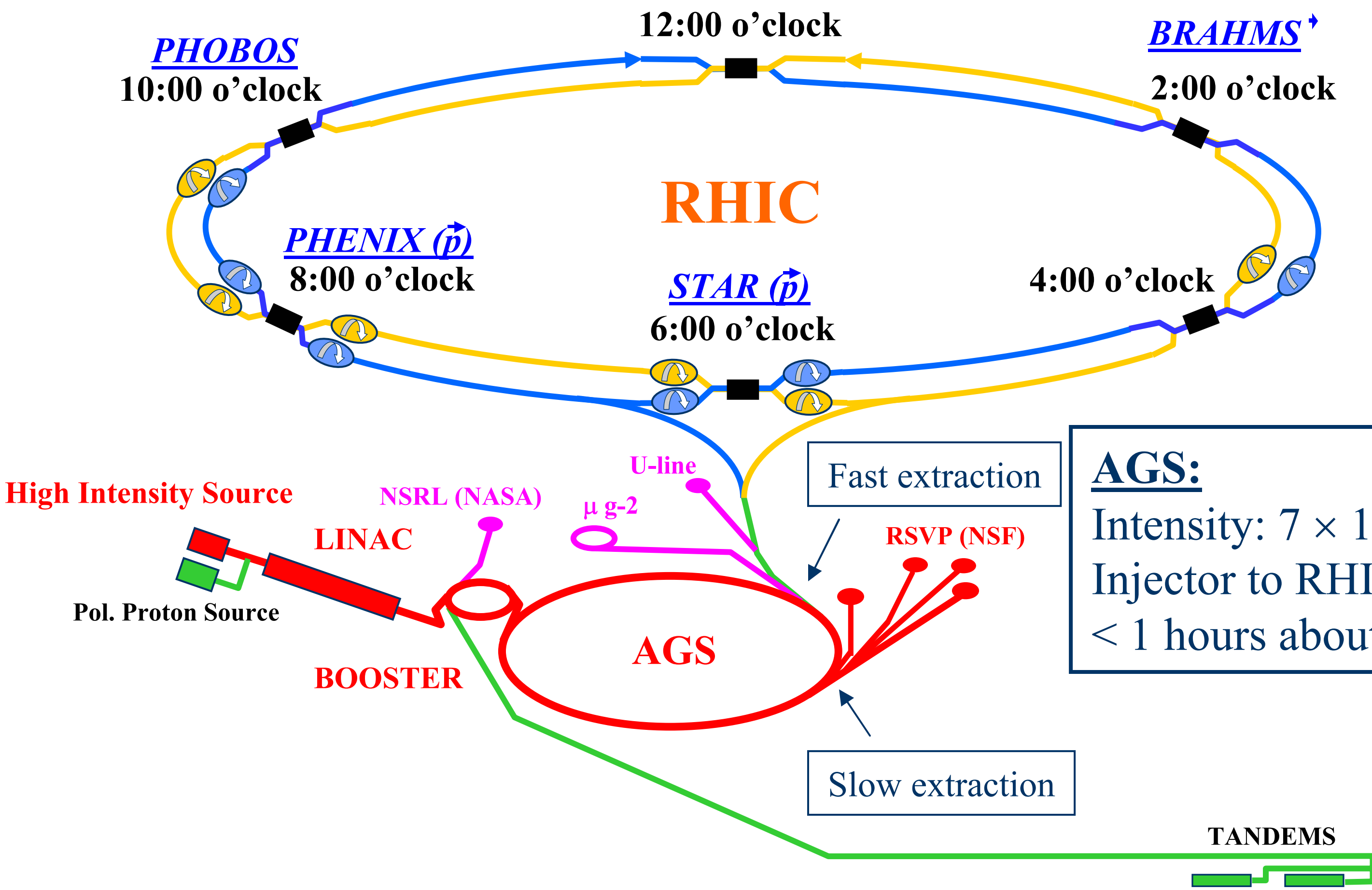
  - Electron beam diagnostic systems,
  - Diagnostics of the cooled ion beam, and
  - A study plan for the ERL prototype

- The committee is aware that the electron cooling project is of critical importance to the RHIC upgrade and it recommends that every effort be made to bring this project to a success.

- The committee would like to mention that in view of the challenges to be met, the human resources dedicated to the accelerator physics and overall design issues appear to be quite small.

RSVP Impact

AGS/RHIC Accelerator Complex



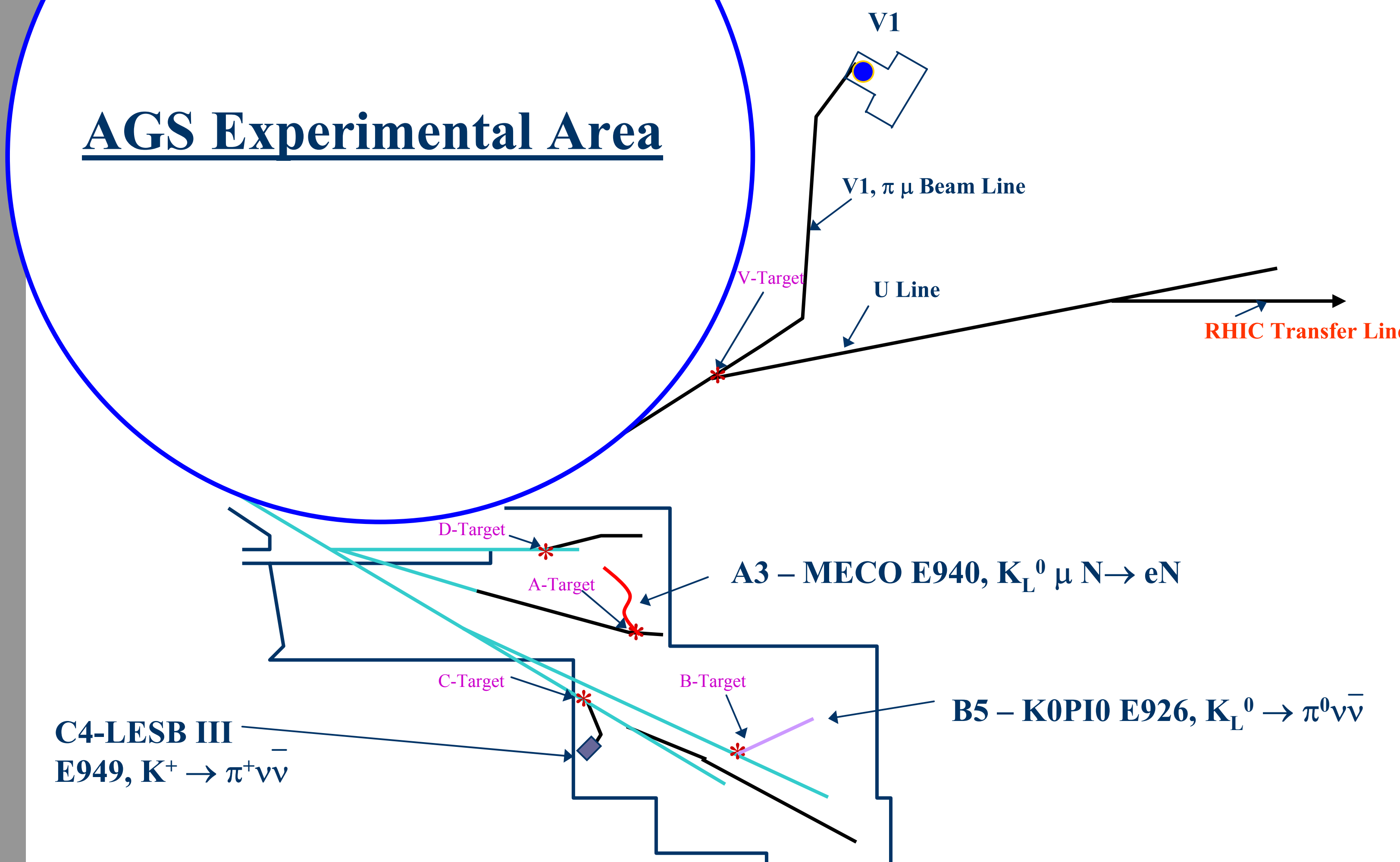
AGS:

Intensity: 7 × 10^{13} protons/pulse

Injector to RHIC:

< 1 hours about every 4 hours

AGS Experimental Area



DOE Review of RSVP Project

January 27-28, 2004

D. Lehman (DOE), S. Tkaczyk (DOE), R. Ehrlich (Cornell), S. Gourlay (LBNL),
K. Lang(Texas), P.Limon (Fermilab), R, Mau (Fermilab), R. Lutha (DOE),
P. Barnes (LANL), R. Macek (LANL)

DOE: D. Kovar, J. Hawkins, S. Steadman, A. Byon-Wagner, R. Desmaris, M. Butler
NSF: M. Coles, M. Goldberg, J. Lightbody, J. Stone, J. Whitmore

- **Findings relevant to the Charge:**
  - **There appear to be no insoluble issues concerning RSVP construction or operation that would have a negative impact on the operation of RHIC as presently envisioned.**
  - **There appear to be no issues concerning E949 operation that would have a negative impact on the operation of RHIC as presently envisioned.**
  - **Preparing the Booster and AGS to operate more reliably and at higher intensity, and the additional highly-trained personnel brought on staff for RSVP is likely to have a positive effect on the operation of the RHIC injector chain and even on the collider itself.**

- **Comments**

  There are some issues that could have an impact on RHIC operation

  - **Increased beam intensity and more AGS operation could result in higher failure rates or longer repair and maintenance times which could negatively affect RHIC operation.**
    - **This is particularly true for the MECO run plan because of increased average intensity.**
    - **This problem can be solved by limiting beam loss to an acceptable level. This solution may result in increased running time for RSVP by as much as a factor of two. Hence, it is not the preferred solution. This is done routinely for AGS high intensity operations.**

- **Additional Comments**

  There is at least one possible effect on other BNL operations

  - **Operation of the NSRL will require changes if operated in conjunction with MECO, due to the high repetition rate of MECO.**
    - **It is likely that this can be solved by intelligent scheduling or changes in the NSRL spill structure.**

- **More comments**

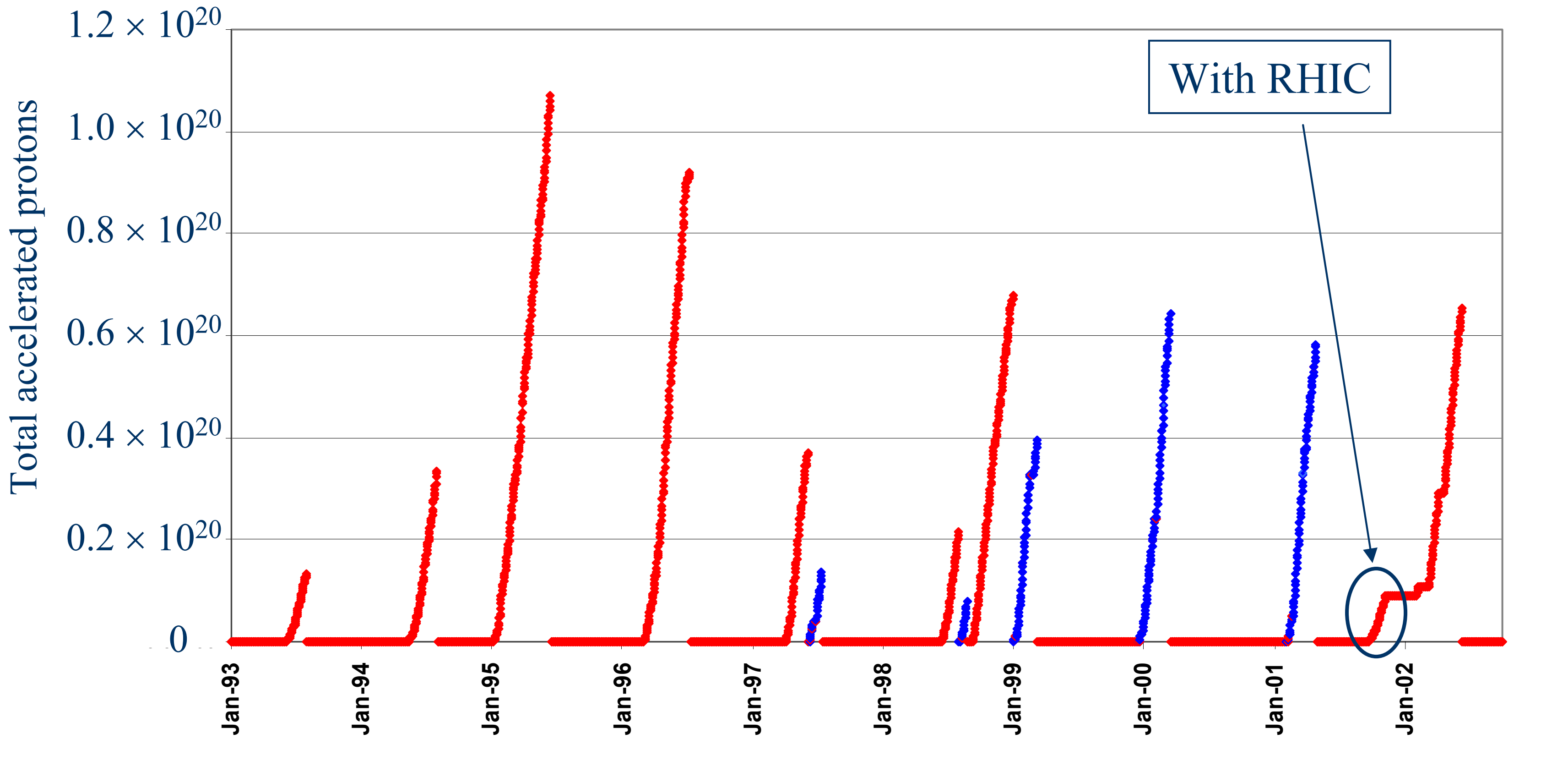
  These experiments are very challenging and require the highest beam intensity and smoothest operation. This raises some issues for the AGS and its injectors. These issues do not affect RHIC operation.

  - **The biggest challenge involves beam loss and component irradiation. If not solved, this could result in either increased failure rates and longer time to repair, or administratively imposed lower beam intensity and longer running time.**

- **Some plausible solutions exist for this issue, but they require testing and R&D to raise confidence that they will work.**
  - **Bunch intensity and losses at a cycle always below AGS transition could be studied now, with no additional equipment.**
  - **Extraction efficiency at 8 GeV could be studied now.**
  - **Beam loss at AGS injection must be reduced, and intensity increased. This could be studied if kickers and a few other components for higher injection energy existed and were installed in the Booster-to-AGS line.**
  - **Microbunching, extinction and spill structure for KOPIO could be studied with the addition of a 25 MHz cavity.**
- **There are other accelerator-related issues that could be studied in a timely fashion.**
  - **Extinction for both experiments, for example. Recent KOPIO test yielded 10^{-5} extinction, where 10^{-3} is specified.**
  - **Intensity dependence of losses and beam stability**

- **Recommendations**
  - **Solutions to some accelerator-related issues are required for these experiments to succeed. It would be good to know for sure that there are solutions to these potential problems. Invest some R&D funds now to solve the most pressing of these problems.**
    - **None of these solutions require large investments, and the returns will make it possible to move forward with confidence.**
    - **KOPIO extinction study was the first such test.**
  - **Find ways to shorten the construction & commissioning period and the required calendar running time.**

Total Accelerated Protons at the AGS



Note: Lower total accelerated protons in later years due to much shorter running time

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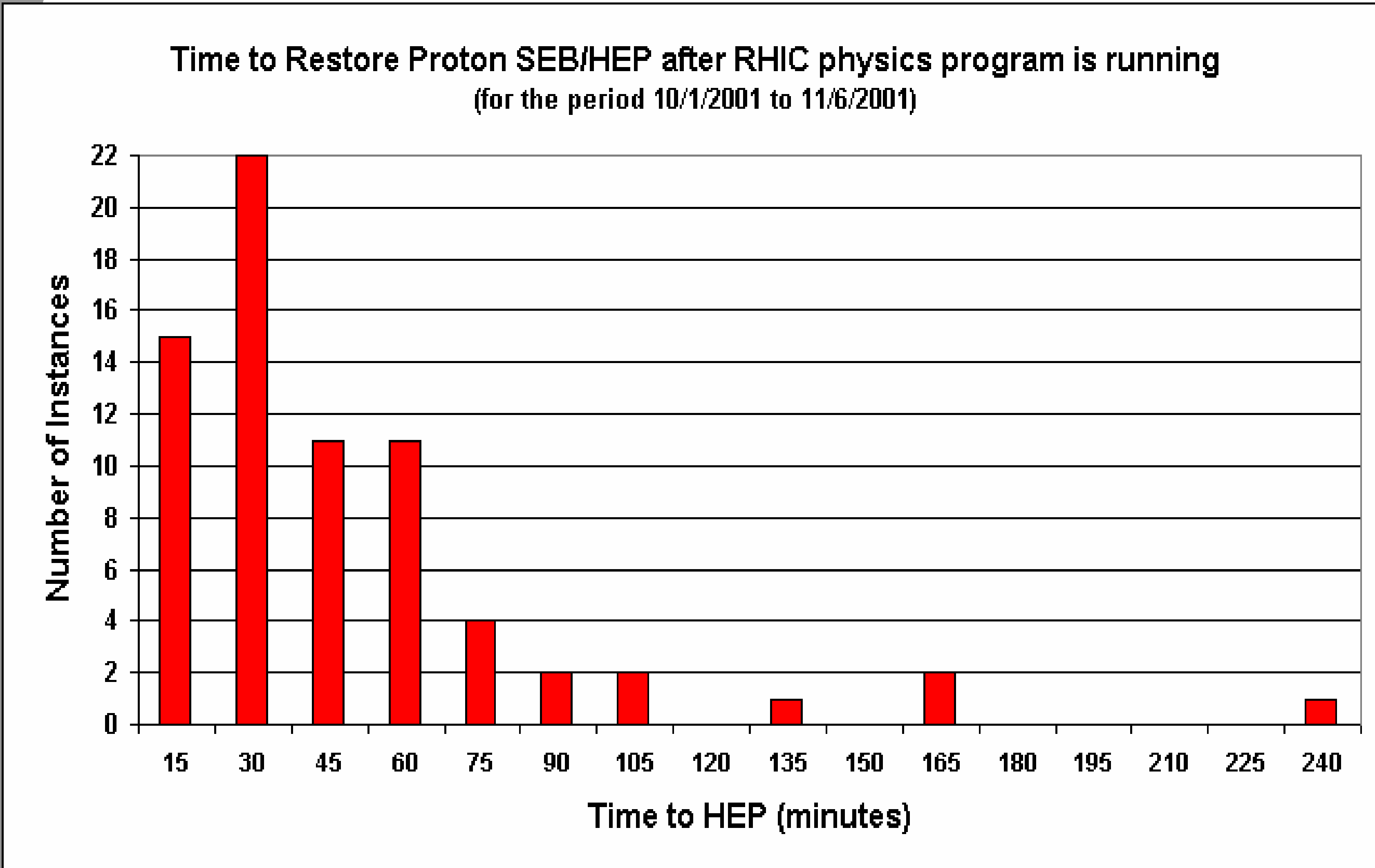

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NASA Space Radiation Laboratory Impact

- **NSRL**
  - Construction was completed on schedule (6/03) and below budget of $34M
  - Booster synchrotron modifications **did not interfere** with RHIC operations
    - Completed during RHIC shutdown periods
  - Tandem modifications (partial NP support) provided a spare RHIC preinjector and made d-Au possible. A **positive impact**.
    - This has been used several times during RHIC operations
  - Beam and experimental area construction was decoupled from accelerator operations
  - NSRL operations was rapidly brought online with the base C-A and new staff, and was shown to be operable in a pulse-to-pulse mode of operation with downstream AGS and RHIC operations.
  - **Additional positive impacts**
    - Matrix RHIC and new hires to support BAF construction and C-A operations
    - NASA supported operations staff increase allows for enhanced RHIC support
    - NSRL commissioning resolved a long standing Booster performance problem

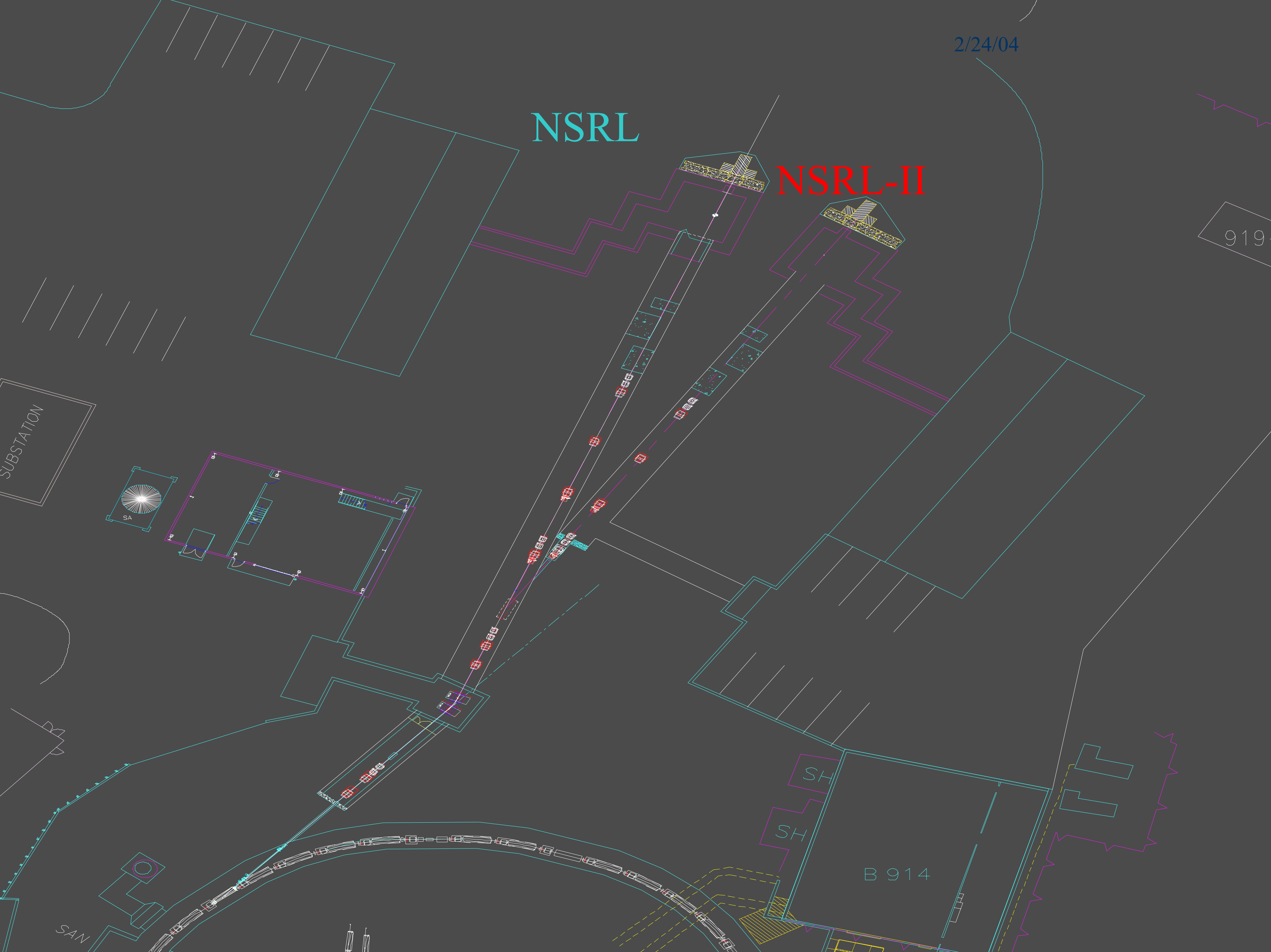
protons to gold

slow extracted

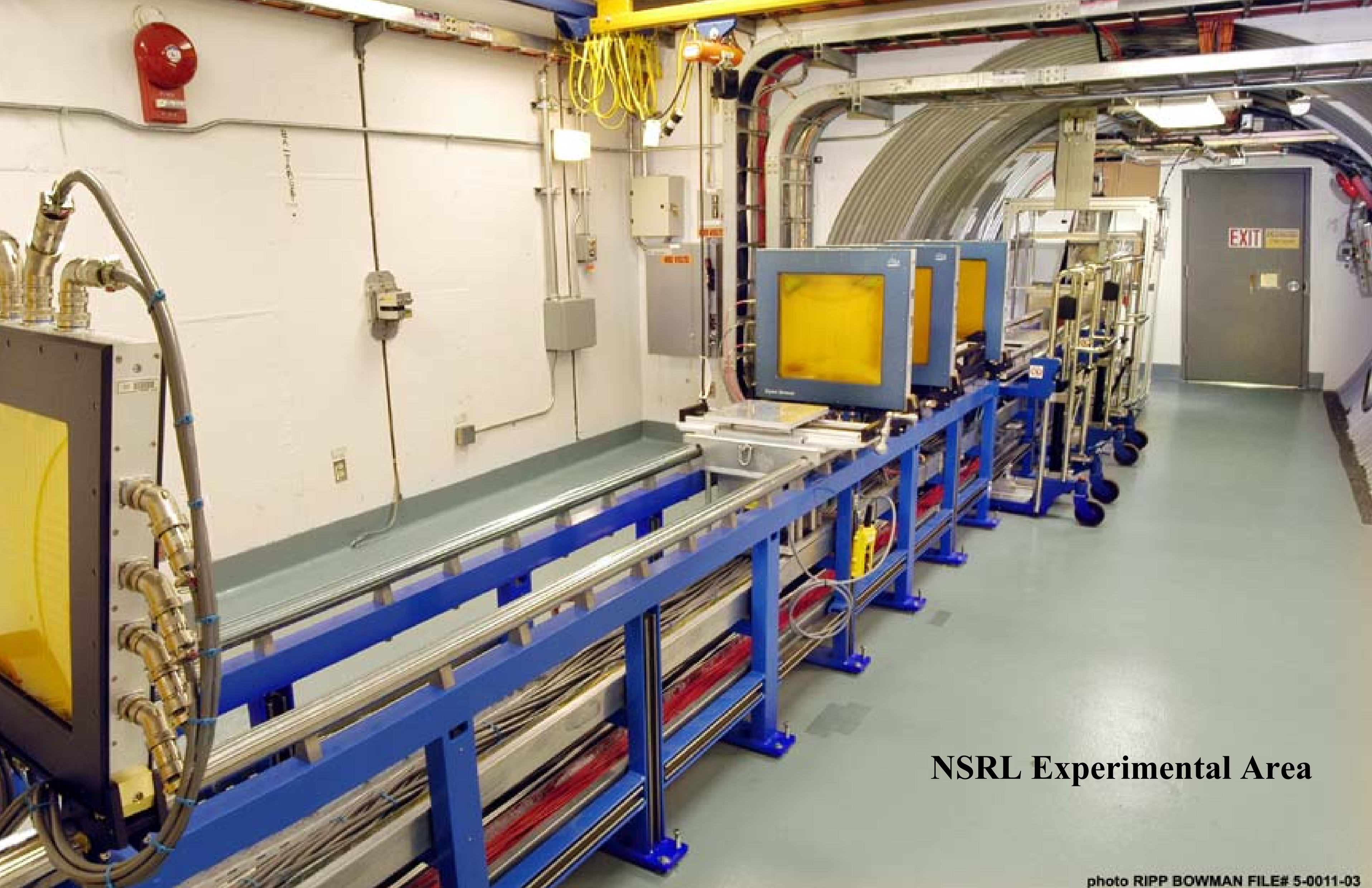
40-3000 MeV / nucleon

NSRL Operations and RHIC

- NSRL operations is secondary to RHIC
  - 2 ion species collision mode may preclude NSRL operations
- 3-4 campaigns per year as per NASA RFP call
  - 150-300 hours per campaign
  - coordinated beam species requirements per campaign
    - including protons and ions
- 10-12 hour /day, 5 days /week operation
  - includes beam setup time
  - will entertain physics experiments for other times



2/24/04
NSRL
NSRL-II
SUBSTATION
SA
B 914
SH
SH
SAN
919



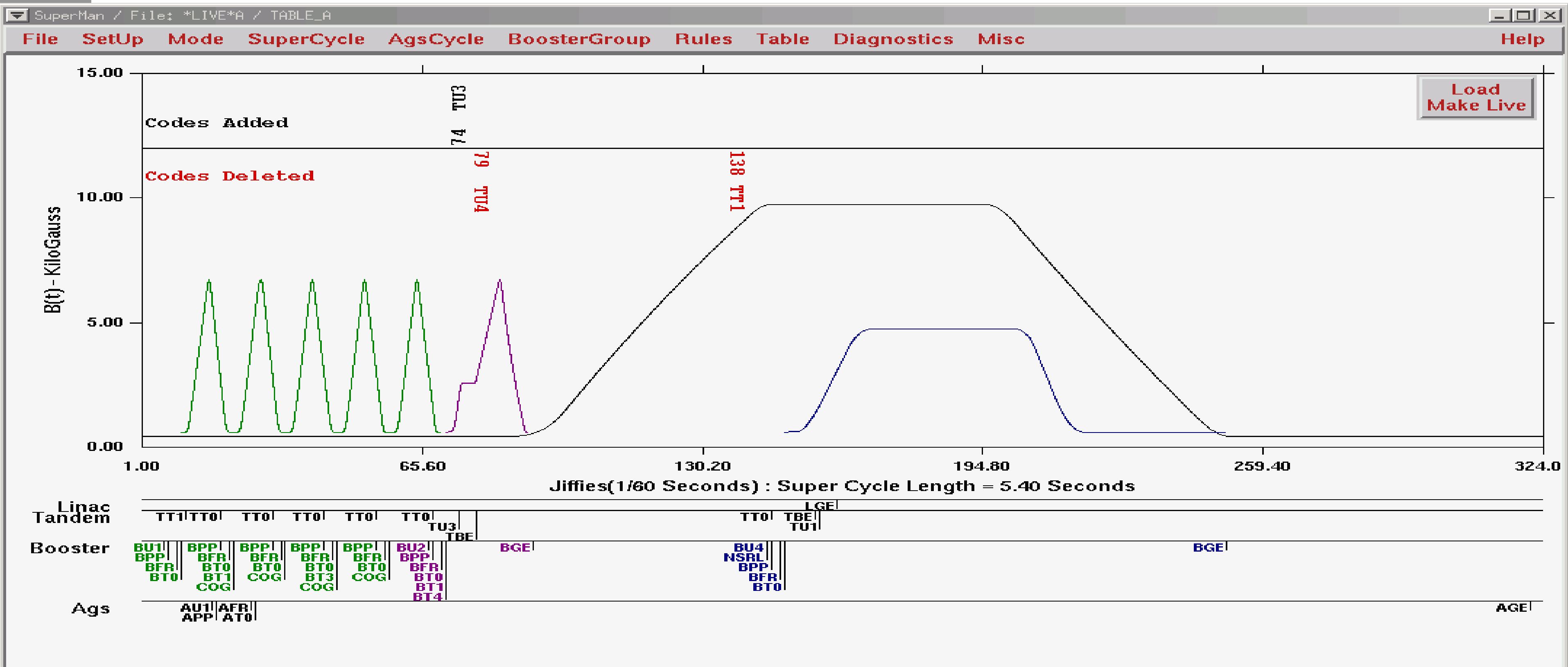
NSRL Experimental Area

photo RIPP BOWMAN FILE# 5-0011-03

NSRL schedule

- First run (NSRL-0) began July 9, 2003
  - 150 hours run
    - carbon (290 MeV), titanium (1.1 GeV), iron (1.0 GeV)
    - no RHIC operations
- Second run (NSRL-1) began October 27, 2003
  - 294 hours run
    - carbon (290 MeV), iron (800 MeV, 1.0 GeV), titanium (1.1 GeV)
    - RHIC injector turn-on concurrent
- Third run (NSRL-2) began March 15, 2004
  - 458 hours run
    - carbon (290 MeV), iron (600 MeV, 1.0 GeV), silicon (600 MeV), titanium (1.1 GeV)
    - RHIC operations
- Fourth run (NSRL-3) began June 7, 2004
  - 300 hours scheduled
    - iron (600MeV, 1.0 GeV), protons (1.0 GeV)
    - No RHIC operations

Injector Super cycle, November 2003



The Injector Super cycle showing (green) 5 Booster magnet cycles for RHIC gold

(1 conditioning cycle and 4 production cycles),

then (purple) 1 Booster cycle for gold merge development, then (blue) 1 Booster NSRL cycle.

The black function is the AGS main magnet cycle to accelerate the four gold transfers.

Summary RHIC machine performance

- **Significant progress in Run-4 (FY04)**
  - Integrated Au-Au luminosity increased 15× compared to Run-2
  - Less than 2 days set-up for lower Au energy run
  - 1st measurements with polarized H jet target (store and injection)
  - Demonstrated viability of long polarized proton run
    (repeated stores with P=35%, $L=5\cdot10^{30}cm^{-2}s^{-1}$ initially)
- **Preparations for Run-5 (FY05) under way**
  - Substantial vacuum upgrade for more luminosity, many other efforts
  - Ions lighter than Au can be prepared for RHIC
  - AGS cold snake to be finished for Run-5 (probably not used for production)
- **Beyond Run-5: Enhanced Luminosity Goals** (before e-cooling)
  - For Au-Au, average per store, 4 IRs
    $L = 8\cdot10^{26}cm^{-2}s^{-1}$ at 100GeV/u
  - For p↑-p↑ average per store, 2 IRs
    $L = 6\cdot10^{31}cm^{-2}s^{-1}$ at 100GeV
    $L = 1.5\cdot10^{32}cm^{-2}s^{-1}$ at 250GeV
    with **70% polarization**